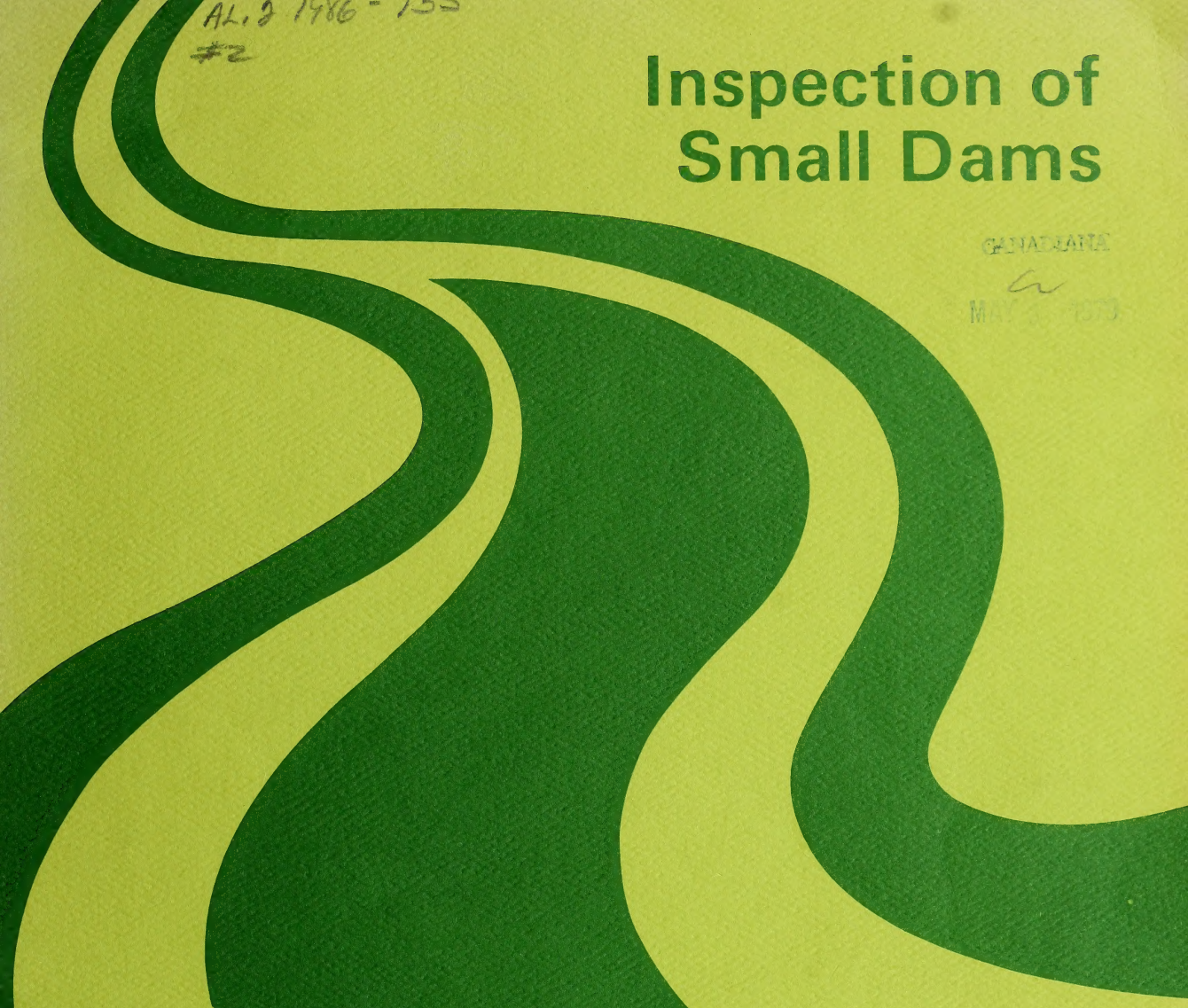
AL.2 1486 - 135
#2

Inspection of Small Dams

CANADIANA
MAY 1973



Alberta

ENVIRONMENT
Dam Safety Branch
Publication D.S.5

DON
5672143

CANADA NATIONAL LIBRARY
BIBLIOTHÈQUE NATIONALE
GOVERNMENT PUBLICATIONS
PUBLICATIONS DU GOUVERNEMENT

General information concerning the inspection of dams may be obtained from:

Dam Safety Branch
Design and Construction Division
Alberta Environment
8th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta
T5K 2J6

Phone: 427-6150

THE WATER RESOURCES ACT
DAM AND CANAL SAFETY REGULATION
INSPECTION OF SMALL DAMS

TABLE OF CONTENTS

PAGE

List of Photos ii

I Introduction 1

II Purpose of this Pamphlet 1

III Elements of a Dam 1

A. General 1

B. Main Embankment and Foundation 1

C. Main and Emergency Spillways 3

D. Riparian Outlets 3

IV Inspection Guidelines 3

A. General 3

B. Seepage 6

C. Erosion 7

D. Cracks 10

E. Embankment Slides 11

F. Spillways 13

G. Riparian Outlets 14

H. Miscellaneous 15

LIST OF PHOTOGRAPHS

Photo No.		Page No.
1 and	2 Breached dam	5 & 6
	3 Seepage marsh located immediately downstream of the embankment	6
	4 Piping failure adjacent to conduit	7
	5 Deterioration of the riprap has resulted in unprotected areas on the upstream slope	8
6 and	7 Eroded upstream slope	8
	8 Eroded downstream slope	9
	9 Well riprapped upstream slope	10
	10 Well maintained downstream slope	10
11 and	12 Longitudinal cracks in the embankment	11
	13 Embankment slide on the downstream slope	12
	14 Extensive erosion at the spillway resulted in the failure of the control structure	13
	15 Eroded spillway channel	13
	16 A silted conduit inlet	14
	17 A bent control shaft makes this riparian outlet inoperable	14
18 and	19 Overtopping of this dam caused extensive erosion to the downstream slope	15
	20 Tree growth on the embankment slopes is undesirable	16
	21 Shrubs obscure the embankment slopes making inspections difficult	16

Digitized by the Internet Archive
in 2015

https://archive.org/details/waterresourcesac00albe

THE WATER RESOURCES ACT
DAM AND CANAL SAFETY REGULATION
INSPECTION OF SMALL DAMS

I INTRODUCTION

This pamphlet has been prepared by the Dam Safety Branch, Design and Construction Division, Alberta Environment to provide dam owners information and guidelines for making visual safety inspections. The pamphlet is not intended to be used as a design guide. Routine inspections will enable dam owners to detect problems at an early stage, thereby minimizing the risk of serious structural damage. Dams that appear in good condition should not be eliminated from an inspection program, since certain conditions may not be evident with a single inspection. Problems can develop or progress at any time, especially following severe storms or heavy rains.

Section III provides a brief description of a typical dam and its components. Section IV outlines the actual inspection of a dam, indicating various problems that can arise and a course of action to be taken once a problem is identified.

It should be emphasized that if a problem is not corrected, it may lead to serious damage or to an eventual failure. When a problem is detected or if in doubt, the owner should seek the advice of a qualified professional engineer experienced in the design of dams.

II PURPOSE OF THIS PAMPHLET

This pamphlet is aimed at the owners of dams and canals that operate their structures privately (i.e. without the benefit of an organization that has engineers on staff). By using this pamphlet, it is hoped that these owners will be able to recognize potential dangers to their structures. They will then be able to obtain a professional engineer's advice before a serious failure occurs.

The Dam Safety Branch in the course of its administration of the Dam and Canal Safety Regulation, Alberta Regulation 351/78, will be making inspections periodically of all of the dams within the province that exceed 25 feet or more in height or exceed 50 acre-feet in capacity.

III ELEMENTS OF A DAM

A. GENERAL

Throughout the province of Alberta, dams are constructed to serve various purposes: diversion, flood control, hydroelectric power, irrigation, mine tailings storage, recreation (boating and fishing), stockwatering, water supply (domestic and industrial) and waterfowl propagation.

A dam is an artificial barrier which does or is capable of impounding or diverting water. Earthfill dams consist of a main embankment and can include any of the following structures: dykes, spillways, emergency spillways and riparian or canal outlets.

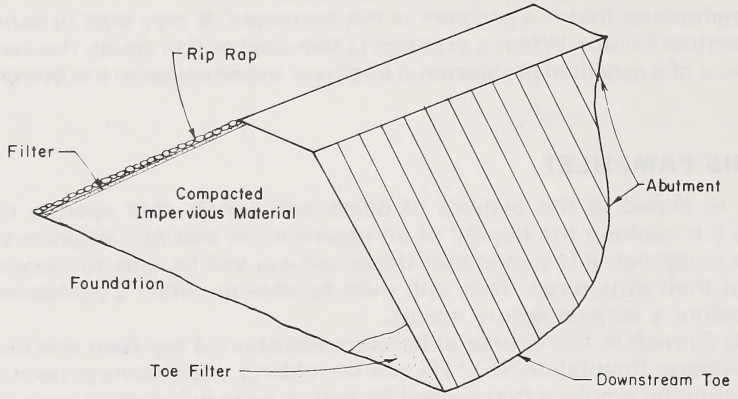
B. MAIN EMBANKMENT AND FOUNDATION

The main embankment, which is usually constructed across a natural water course, and any dykes which may be required, serve to impound water in the reservoir. Earthfill dams are classified either as homogeneous or zoned fill structures. Homogeneous embankments consist of essentially the same type of material throughout the structure. The soil used as embankment material should contain at least 20 - 30% clay, however, very high contents of clay should be avoided since excessive shrinkage may result. A granular filter should be constructed extending into the dam from the downstream toe to intercept any seepage that may otherwise break out along the downstream slope. Homogeneous embankments can be constructed at a relatively low cost and are usually

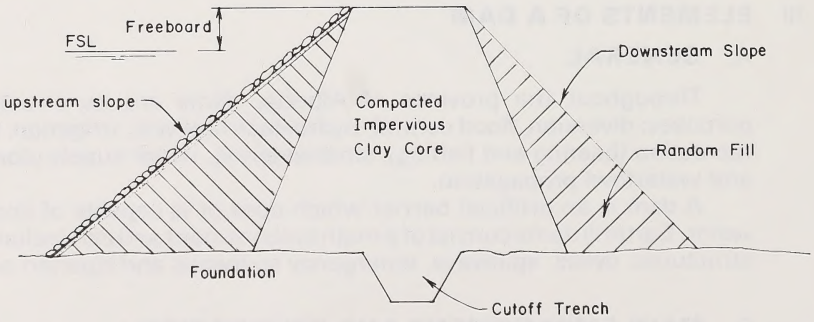
used in the design of smaller structures. Zoned embankments are constructed in areas that possess sufficient clay and granular materials. With this type of design, a central core of well compacted clay material acts as an impermeable boundary to retain water in the reservoir, while stability and drainage is provided by outer layers of granular material. Zoned embankments are more expensive to construct than homogeneous embankments, but can be constructed at a quicker rate and are usually used in the design of larger structures. Whenever possible, a zoned fill embankment should be used since it has greater long-term stability. Upstream slopes of embankments are usually protected from wave erosion by a layer of clean gravel known as a filter and a layer of rock known as riprap.

The natural ground above the valley bottom against which the embankment is constructed is called the abutment. Proper placement and construction techniques are required to ensure a good soil contact at the abutments.

Foundation materials at dam sites should possess sufficient strength to provide support for the embankment. Low permeability is a desired characteristic of a foundation material in order to minimize seepage beneath the embankment. If the permeability of a foundation material is excessive, impermeable blankets, cutoff walls, or core trenches can be constructed to decrease seepage losses. Figure I illustrates two cross-sections and defines various elements of a dam.



A. Homogeneous Embankment



B. Zoned Embankment With Cutoff Trench

Figure I Typical embankment cross sections.

Two main objectives in designing a dam are to minimize seepage losses and to provide the greatest amount of stability for the structure. Since all soils are permeable to some degree, a certain amount of seepage can be expected to eventually flow through the structure. Toe drains and various types of filters are incorporated into the downstream slope of a dam to intercept any seepage that may be flowing through.

C. MAIN AND EMERGENCY SPILLWAYS

All dams are designed with a specified maximum elevation to which the reservoir level can be raised. This elevation is known as the full storage or full supply level (FSL). Main spillways are constructed to pass water from the reservoir to the downstream channel whenever water levels exceed FSL. Emergency spillways are constructed at a slightly higher elevation than main spillways so that they will be used when the capacity of the main spillway is exceeded. Spillways should allow for safe passage of water from the reservoir to the downstream channel, without being susceptible to or creating erosion downstream.

Metal or concrete pipes, concrete or timber chutes, and earthen channels are the most common types of main spillways. Since emergency spillways are only used during periods of unusually high water levels, their operation is infrequent. For this reason they usually consist of natural or excavated earthen channels.

D. RIPARIAN OUTLETS

Riparian outlets are low level outlets capable of draining the reservoir. During periods of excessive rainfall, a riparian outlet can be opened to lower the reservoir in anticipation of a flood. By lowering the reservoir, chances of overtopping the dam are decreased. Riparian outlets are used to discharge water from the reservoir in areas that require a specified minimum amount of water to be discharged downstream, as outlined in the Water Rights licence.

IV INSPECTION GUIDELINES

A. GENERAL

Early detection of problems can only be made with regular inspections. This will allow dam owners to implement corrective measures before problems become so advanced as to reduce the overall stability of the dam. A thorough annual inspection should be made of the embankment slopes, crest, toe, abutment areas, and any associated spillways or drains.

Failure of earth dams can be classified into three basic modes, hydraulic, seepage, or structural, depending on the cause of failure. Hydraulic failures result from uncontrolled flow of water over dams, at spillways and outlets, from surface runoff, or from continual erosion by waves in the reservoir. Material being transported away from the downstream slope or from beneath the embankment by seepage flows may eventually lead to a seepage or piping failure. Structural failures are caused by weak or unstable embankments and foundations that are unable to resist forces created by water in the reservoir or by the weight of the embankment material. Tables I, II, and III provide a summary of hydraulic, seepage, and structural failures indicating various causes and preventive measures. Two breached dams are shown in Photos 1 and 2.

TABLE I — HYDRAULIC FAILURES

Form	Characteristics	Causes	Preventive Measures
Overtopping	Flow over embankment, washing out dam.	Inadequate spillway capacity.	Spillway to be designed for maximum flood.
		Clogging of spillway with debris.	Install trash racks where possible or remove debris when accumulated.
		Insufficient freeboard due to settlement of embankment.	Increase crest elevation.
Wave erosion	Erosion of upstream face by waves.	Insufficient protection against erosion.	Placement of well-graded riprap and filters.
Toe erosion	Erosion of embankment toe by spillway or outlet discharge.	Spillway or outlet located too close to dam.	Concrete chute should be constructed to safely discharge water downstream of the embankment.
		Inadequate riprap.	Placement of well-graded riprap including large boulders to withstand the force of the water.
Erosion gullies	Surface runoff eroding face of dam.	Poor surface drainage and lack of adequate grass cover on the downstream slope.	Provide drains or ensure adequate grass cover on downstream face.

TABLE II — SEEPAGE FAILURES

Form	Characteristics	Causes	Preventive Measures
Piping or Seepage erosion	Progressive internal erosion of material from downstream side of dam or foundation toward upstream which eventually leads to a breach in a dam section.	Concentrated seepage along downstream slope.	Install toe drains or filters.
		Seepage along conduits.	Grouting along conduit to fill voids; replacement of conduit with proper construction techniques implemented.
		Leaking conduits.	Seal joints; grouting.

NOTE: In many instances water losses and piping develop with the presence of pervious foundation materials. Cutoff walls, key trenches and drains or filters should be installed during construction to overcome this problem. Removal of compressible foundation materials and adequate compaction are necessities during construction to minimize formation of settlement cracks. Voids created by settlement cracks provide easily accessible paths for potential seepage. Excessive settlement and seepage through foundations and along conduits becomes difficult to prevent or control once a structure is completed. These problems can best be controlled with consciencious construction practices during construction of the embankment and conduits.

TABLE III — STRUCTURAL FAILURES

Form	Characteristics	Causes	Preventive Measures
Foundation slide	Sliding of one slope or both slopes in opposite directions, with bulging of foundation in direction of movement.	Soft or weak foundation.	Flatten slope; construct berms.
		Excess water pressure in foundation.	Provide drainage trenches, filters, or relief wells.
Upstream slope	Slide in upstream face.	Steep slope.	Flatten slope; construct berm.
		Weak embankment soil.	Increase compaction.*
		Rapid reservoir drawdown.	Avoid lowering reservoir by large amount over a short time period.
Downstream slope	Slide in downstream face.	Steep slope.	Flatten slope; construct berms.
		Weak embankment soil.	Increase compaction.*
		Saturation of slope by seepage causing loss in soil strength.	Provide proper drainage.

*NOTE: If a failure occurs during construction due to weak embankment materials, the increased compaction must be provided at that time. Construction failures may require that the embankment be constructed with flattened slopes or additional berms.

PHOTO 1 Breached Dam

PHOTO 2 Breached Dam

B. SEEPAGE

The hydraulic head exerted by water in the reservoir tends to force water through and under the embankment. Ideally, an inspection for seepage should be made when the reservoir level is at or near FSL, since maximum head or seepage force is attained during this period. Areas to be examined include the downstream slope, downstream toe, abutments, and areas near spillways and drains. Seepage areas can be identified by wet spots or muddy areas, usually accompanied by the growth of moss on the slope and reeds or cat-tails near the toe. Areas of thicker, greener vegetation usually indicate a seepage area. The darker area downstream of the embankment toe as shown in Photo 3 is an example of a typical seepage marsh. Placement of stakes around the perimeter of a seepage area provides a good reference in determining if the wet area is remaining stable or increasing in size.

PHOTO 3 Seepage Marsh Located Immediately Downstream of the Embankment

Embankments and foundations are not totally impermeable, therefore, small amounts of seepage (not concentrated flows) emerging at the toe or downstream of the embankment is not a serious condition, as long as proper drainage is provided and ponding is not allowed to occur. Excessive quantities of seepage or the formation of marshy areas immediately below the embankment toe warrant an investigation by a professional engineer.

Seepage emerging along the downstream slope (i.e. above the toe line) tends to saturate the surrounding material. This may lead to an embankment slide, since saturated soils have reduced strength and therefore less capability to support the weight of the overlying material. Both abutments should be examined for seepage along the contact line. Wet spots at the abutments may indicate a poor bond between the embankment and natural ground surface, which essentially becomes a weaker zone of material susceptible to failure. The appearance of flowing water from a well defined hole is known as "piping." If the water appears muddy or contains sediments, material is probably being eroded from within the embankment and a piping failure could rapidly develop as shown in Photo 4. Detection of any of these conditions, seepage at the abutments, seepage along the downstream slope, or piping requires the immediate attention of a professional engineer.

PHOTO 4 Piping Failure Adjacent to Conduit

C. EROSION

The upstream slope of the embankment should be examined for any signs of erosion or beaching, which is caused by constant wave action in the reservoir. Beaching is characterized by the initiation and progressive development of vertical sections in the upstream slope, resulting from inadequate erosion protection.

An examination of the riprap should be made to determine if proper erosion protection is being provided. Deterioration of the riprap as shown in Photo 5 exposes the embankment material which becomes susceptible to erosion. The size of riprap used has a bearing on the amount of protection provided. An over abundance of larger rocks allows water to wash between them and underlying filter or embankment material can be carried away. Riprap containing mainly smaller stones can be transported into the reservoir, since their weight may be insufficient to withstand the force of larger waves. Properly designed riprap must contain a mixture of large rocks and small stones (i.e. be well graded) to provide adequate protection. Embankment material must be protected from internal erosion by properly designed filter zones. Eroded areas in the upstream slope that become evident should be upgraded with additional riprap to avoid extensive erosion as shown in Photos 6 and 7. Such conditions reduce the stability of a dam.

PHOTO 5 Deterioration of the Riprap has Resulted in Unprotected Areas on the Upstream Slope

PHOTO 6 Eroded Upstream Slope

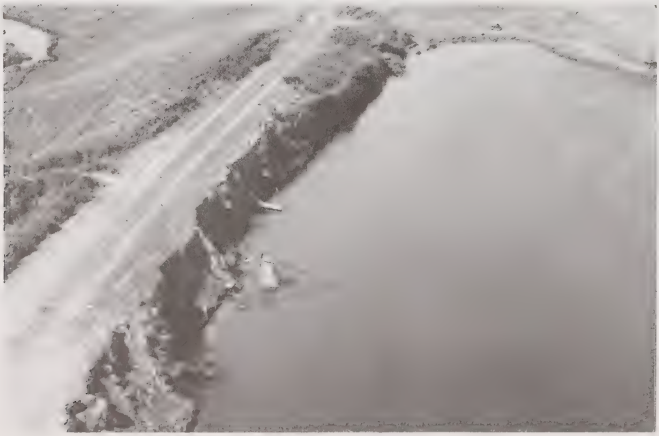


PHOTO 7 Eroded Upstream Slope

Adequate grass cover must be maintained on downstream slopes to avoid erosion of embankment material as shown in Photo 8. In this particular case, material eroded from the upper portions of the embankment accumulated at the downstream toe, blocking a riparian outlet.

PHOTO 8 **Eroded Downstream Slope**

In other instances, excessive amounts of runoff allowed to flow over downstream slopes, at abutments, or in earthen spillway channels can form erosion gullies. Once an erosion gully is formed, it becomes progressively wider and deeper with each successive rainfall or spring runoff. Continued erosion of this form reduces the stability of a dam, therefore, erosion gullies should be backfilled with properly compacted material, with grass or riprap placed at the surface.

Photos 9 and 10 illustrate properly maintained upstream and downstream slopes.

PHOTO 9 Well Riprapped Upstream Slope

PHOTO 10 Well Maintained Downstream Slope

D. CRACKS

Short, isolated cracks appearing on the crest of the dam are usually caused by soil shrinkage and are not a cause for concern. Larger, well defined cracks extending a number of feet in length may lead to further problems. Their dimensions (i.e., length, width and depth) should be measured to provide a comparison on the next inspection. Enlargement of cracks on a dam can develop into serious situations, therefore, a professional engineer should be contacted. Cracks appear on a dam in two forms, transverse and longitudinal.

Transverse cracks run perpendicular to the length of the dam and usually form due to differential settlements in the foundation or embankment material. Deep cracks located on the crest tend to collect surface runoff and may lead to internal erosion or piping. An engineer should be consulted to make an assessment and to recommend the necessary repairs.

Since longitudinal cracks preceed the actual development of a slide, they will be discussed with embankment slides in Section E.

E. EMBANKMENT SLIDES

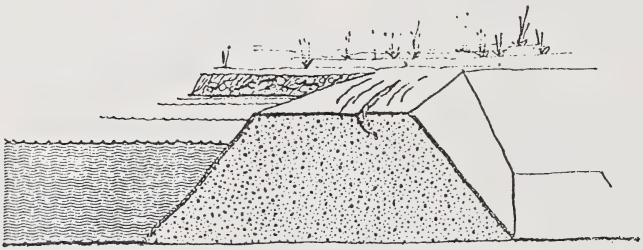
Slides are caused by insufficient slope stability or by a reduction in the strength of the embankment material. Poorly designed slopes or slopes that have developed steeper sections after erosion have less stability and are susceptible to slides. As discussed in Section B, seepage emerging along the downstream slope will reduce the strength of the embankment and can lead to a slide.

Formation of longitudinal cracks, as illustrated in Photos 11 and 12, normally preceed the development of a slide. Longitudinal cracks run parallel to the length of the dam, (i.e. from one abutment to the other) and can form on either slope or on the crest of the dam. If the cracks do not enlarge, the situation may have stabilized but frequent inspections are still required. Once material on one side of a longitudinal crack appears to have settled, a potential slide exists and the dam may be on the verge of a slope failure. If such a situation exists, a professional engineer should be contacted. He may suggest that the reservoir should be slowly emptied through the riparian outlet. A rapid emptying of the reservoir should be avoided for this can instigate a failure of the upstream slope. The progressive development of an embankment slide is illustrated in Figure II and Photo 13.

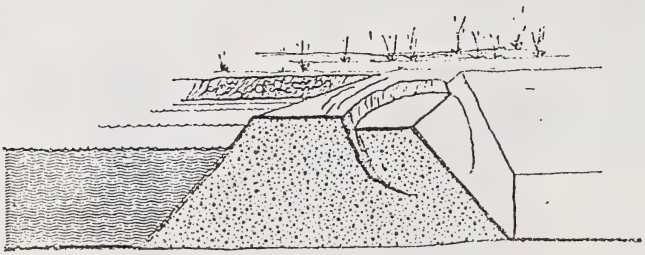
PHOTO 11 Longitudinal Cracks in the Embankment

PHOTO 12 Longitudinal Cracks in the Embankment

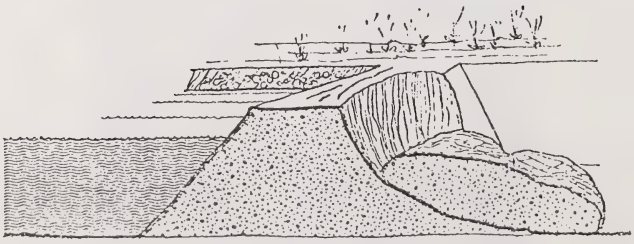
PHOTO 13 Embankment Slide on the Downstream Slope



A. Formation of longitudinal cracks



B. Increased crack lengths and noticeable top settlement



C. Slope failure

Figure II. Cross section showing three-stage growth of embankment side.

F. SPILLWAYS

To ensure that a spillway can discharge its designated capacity, it is essential to keep it free of any obstacles. Trees, shrubs, fences and any debris should be cleared from spillways and spillway channels to avoid overtopping of the dam at higher reservoir levels. Installations of trash racks help to prevent debris from entering the spillway.

Concrete spillways must be inspected for cracks or displacements caused by settlements or frost action. Voids created by the settlement of compressible soils located beneath spillways may cause the spillway to crack or displace, since proper support no longer exists. When temperatures reach the freezing point, water located in the soil voids begins to freeze. As the water freezes, it expands and draws moisture upwards from the underlying soil. This results in the formation of ice lenses, which causes the soil to heave. Spillway cracks and displacements form as the result of soil heaves. Water allowed to enter a crack as it flows through or over a spillway can cause a failure of the spillway by eroding adjacent or underlying material, or by heaving the concrete by uplift forces. Large cracks, extending through the concrete should be grouted or sealed.

A spillway under normal operation should not create or be susceptible to excessive erosion. Scoured areas may develop adjacent to or downstream of the spillway during periods of high discharges. These areas should be upgraded and riprapped with large boulders and proper filters to provide adequate protection. Spillway erosion that is not repaired can lead to a failure of the spillway as shown in Photos 14 and 15.

PHOTO 14 **Extensive Erosion at the Spillway Resulted in the Failure of the Control Structure**

PHOTO 15 **Eroded Spillway Channel**

G. RIPARIAN OUTLETS

The crest of the dam, directly above the riparian outlet should be examined for any evidence of subsidence. This condition can develop in two ways. First, if a hole or crack formed in the pipe, water flowing through the pipe could enter the hole and erode material. Second, water may be flowing along the outside of the pipe directly from the reservoir eroding material in the process. Both cases described are serious problems and a professional engineer should be contacted.

Riparian outlets should be opened periodically to flush out sediments that may be accumulating at the inlet, illustrated by Photo 16. If water is not allowed to flow through the pipe, the inlet may eventually become plugged.

PHOTO 16 A Silted Conduit Inlet

Riparian outlets become inoperable once the control gate is bent or broken as indicated in Photo 17. Control gates should be repaired and always remain operable in case of emergencies.

PHOTO 17 A Bent Control Shaft Makes This Riparian Outlet Inoperable

H. MISCELLANEOUS

Freeboard is the vertical distance between the reservoir level at FSL and the crest of the dam. The amount of freeboard provided varies with the size of the structure or reservoir and the location of the dam. Sufficient freeboard should be provided to ensure that waves will not be washing over the dam when the reservoir is at FSL. If upon inspection, the reservoir level is approaching the crest elevation, the reservoir level should be lowered slightly to avoid overtopping. Water that begins to overtop a dam will cause rapid and serious erosion, demonstrated in Photos 18 and 19.

PHOTO 18 **Overtopping of This Dam Caused Extensive Erosion to the Downstream Slope**

PHOTO 19 **Overtopping of this Dam Caused Extensive Erosion to the Downstream Slope**

Freeboard can be decreased by settlement of the embankment or foundation, or by blocked spillways (discussed in Section F). If a dam appears to have settled, as evidenced by a depression in the crest, a survey may be required for verification. When a dam has settled, additional fill must be placed to restore the freeboard required for the structure.

The reservoir banks should be examined for undercutting and erosion. Depending on the size of the reservoir, a bank slide into the water may cause sufficient

displacement to overtop the dam, or create sediment build up that may reduce the capacity of the reservoir.

Trees or shrubs growing on the embankment slopes are undesirable and should be removed. Large, deep-rooted trees can cause serious damage to an embankment if they were to be uprooted during a violent wind storm. Tree roots can disrupt spillways causing failure of the structure if roots get under the spillway floor, into wall joints, or if they enter joints in pipe spillways. Tree roots also provide a natural seepage path. Shrubs tend to cover the slopes and prevent a proper visual inspection. See Photos 20 and 21.

PHOTO 20 **Tree Growth on the Embankment Slopes is Undesirable**
(Note: Dotted line outlines the embankment)

PHOTO 21 **Shrubs Obscure the Embankment Slopes Making Inspections Difficult**

N.L.C. - B.N.C.
3 3286 06276402 8